TES observations of tropospheric ozone as a greenhouse gas (Climate Related Observations of TES)

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ABSTRACT

Tropospheric ozone is an effective greenhouse gas with a climate forcing comparable, but in the opposite direction to the direct forcing from atmospheric aerosols according to recent assessments of The Intergovernmental Panel on Climate Change (IPCC). These assessments also show significant uncertainties associated with tropospheric ozone and a range of model predictions from 0.25 to 0.65 W/m2 for the radiative forcing due to anthropogenic tropospheric ozone. Much of the uncertainty in the assessment for ozone is associated with the lack of reliable measurements for pre-industrial ozone distributions. However, assumptions of spatial/temporal variability and emissions for ozone precursors are sources of large differences in the model predictions for present and future forcing. Given that tropospheric ozone is highly variable compared to longer lived greenhouse gases such as CO_2 there is a critical need for global observations that can provide constraints for climate model predictions of ozone distributions and forcing.

We present satellite observations of the radiative forcing from tropospheric ozone, for cloud free ocean conditions. This analysis uses infrared (IR) radiance spectra, integrated over the 9.6 micron ozone band between 985 to 1080 cm^{-1}, and ozone profile retrievals from the Tropospheric Emission Spectrometer (TES) on the Earth Observing Satellite (EOS) Aura. We examine the relationship between the outgoing longwave radiation (OLR) in the 9.6 micron band to upper tropospheric ozone and water vapor by separating the data into hemispherical and sea-surface temperature (SST) ranges.

BACKGROUND

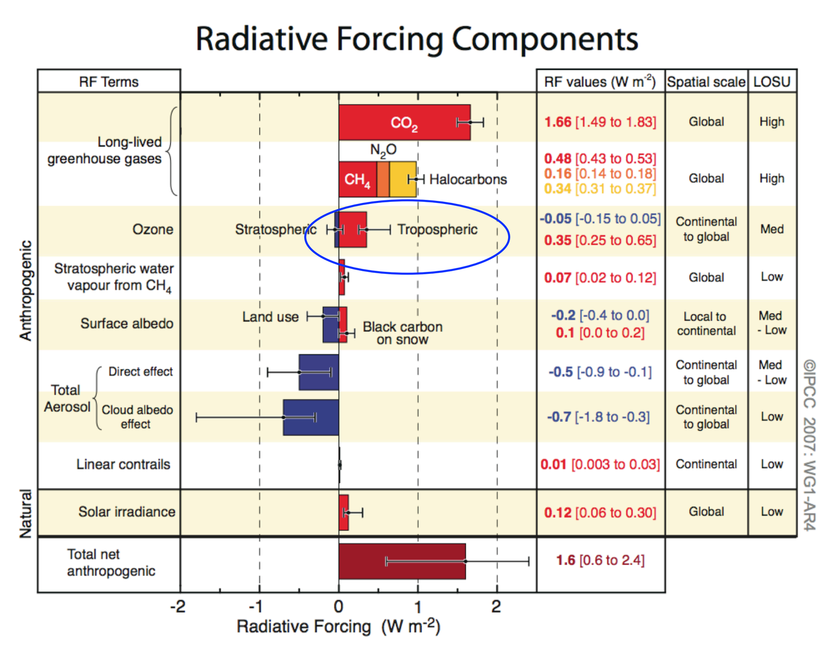


Figure 1. (left) Radiative Forcing budget from the IPCC 4th Assessment Report. Ozone is considered to have a 'medium' level of scientific understanding, but the role of tropospheric ozone is more uncertain than stratospheric ozone.

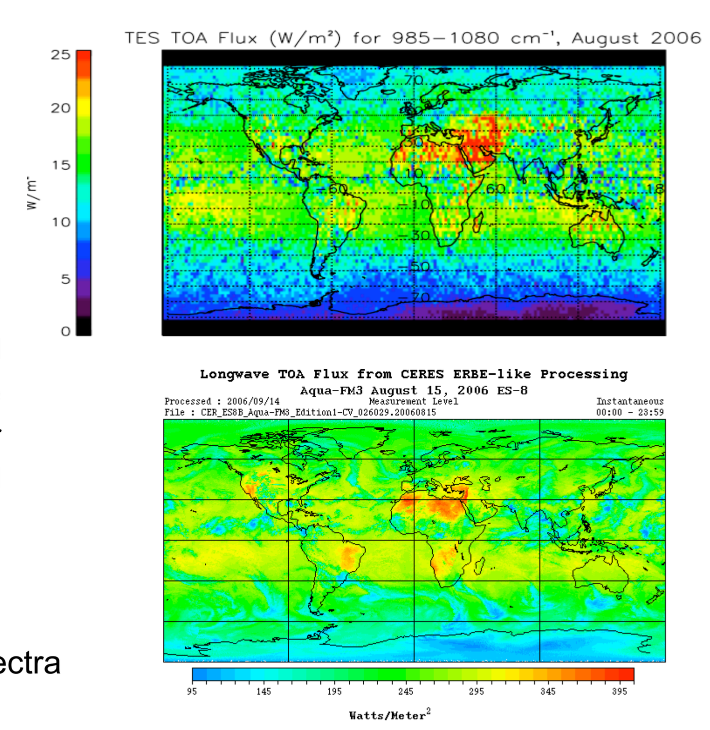


Figure 2. (right) TOA flux in the ozone band observed by TES for August 2006 (upper panel). The longwave TOA flux from CERES for one day is shown in the lower panel. They have similar spatial patterns, and expected differences in magnitude.

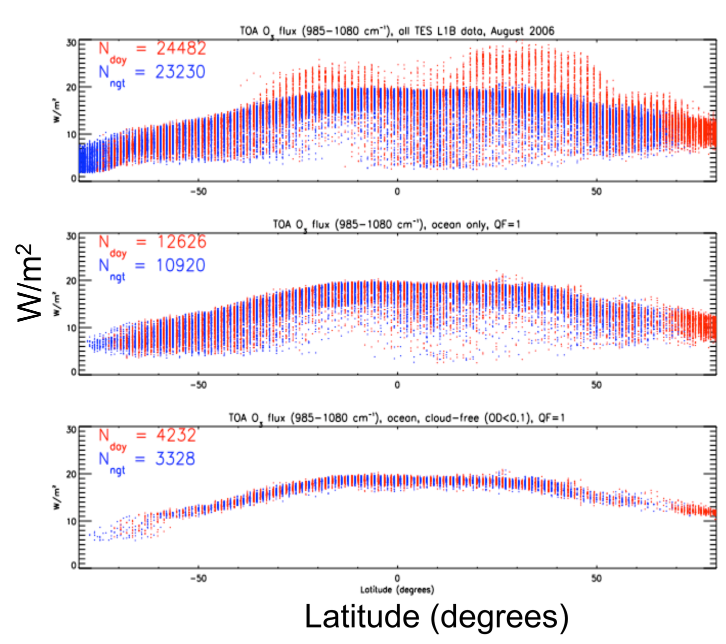
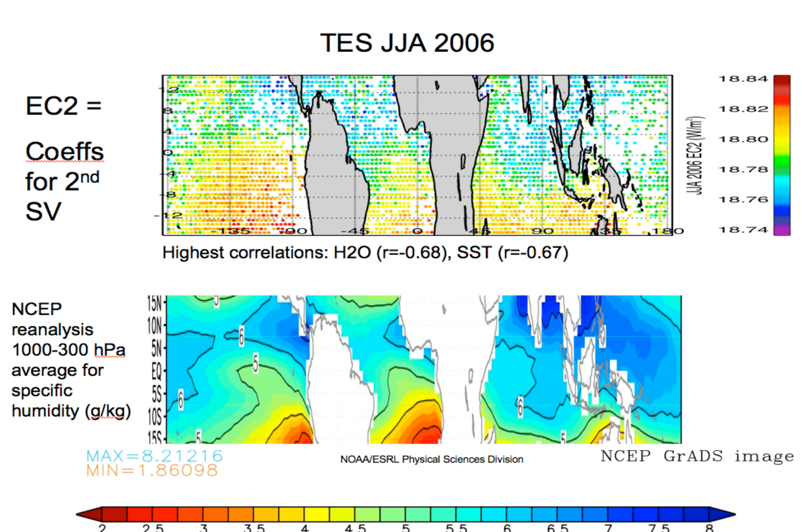


Figure 3. (left) TOA flux on the ozone band for all spectra, and with increasingly strict quality screening for August 2006. With cloud and quality flag (QF) screening, there is little scatter in the data.

ANALYSIS TECHNIQUE

Figure 4. (right) Singular vector analysis was used to identify the dominant variables in the radiance spectra. The expansion coefficients of the second singular vector show spatial patterns close to the NCEP specific humidity, and high correlation (0.67) with water vapor and SST, so these will be isolated in the analysis.



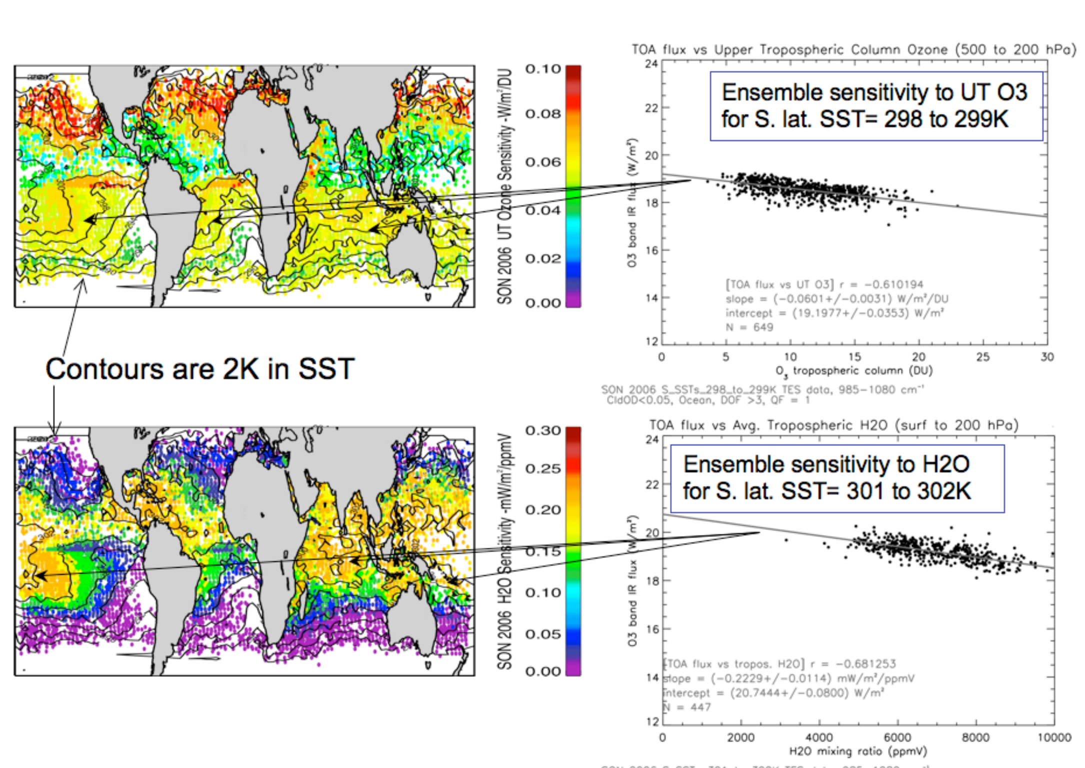
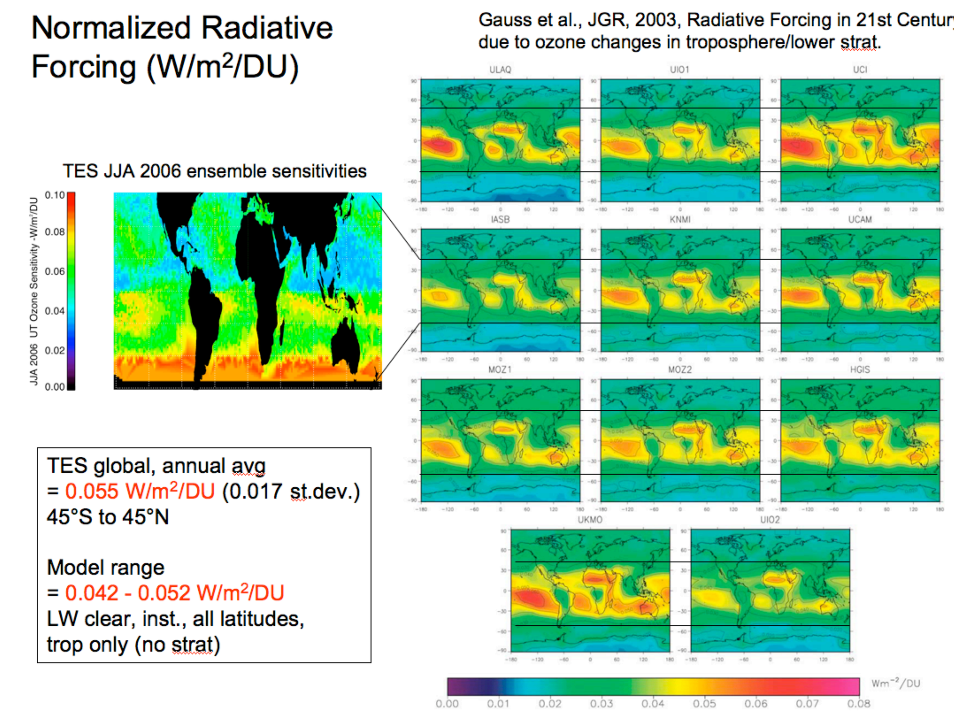


Figure 5. (above) Measurements are grouped in SST bins, and for each bin, ensemble sensitivity of OLR to UT ozone and water vapor is calculated by regression. The sensitivities are in W/m²/DU for ozone, and then are mapped for a global view of the sensitivity.

RESULTS (PART 1)

Figure 6 (right). Map of the ensemble sensitivities of OLR to ozone for the JJA 2006 season derived from TES measurements. Model calculations from Gauss et al are shown on the right, which are calculated based on predicted ozone changes over the next century.



RESULTS (PART 2)

Figure 7 (right). Annual average (2006) UT ozone and water vapor forcing in the ozone band derived from TES, derived from the sensitivty and ozone and water vapor fields. This is now in W/m², and shows the largest ozone forcing in the NH.

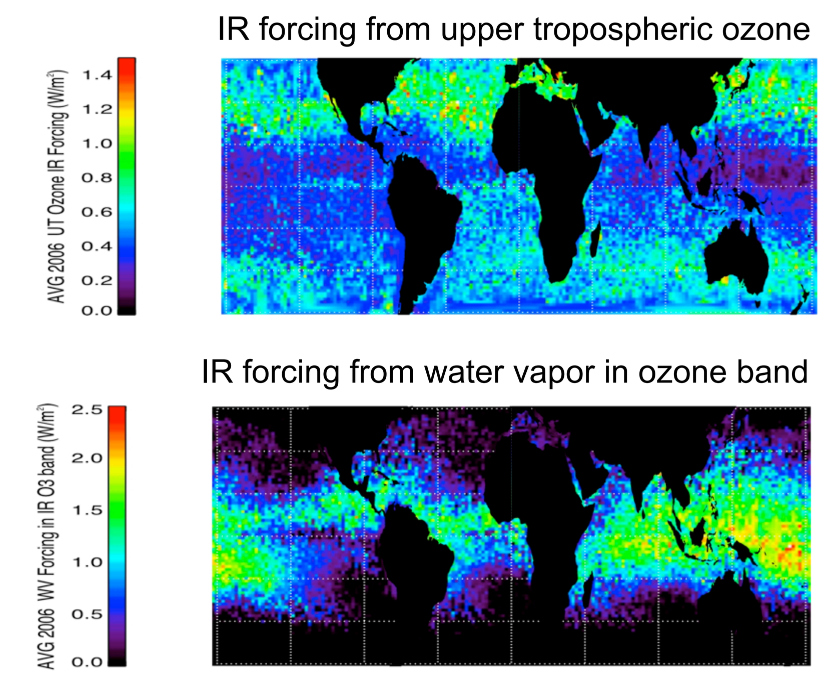
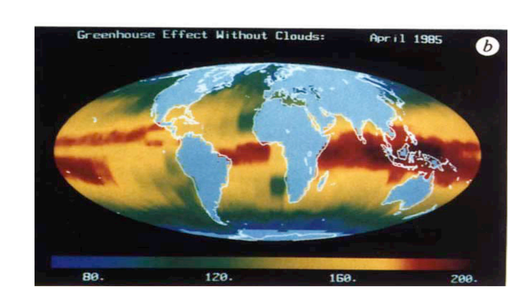


Figure 8 (right). Map of greenhouse effect of water in clear sky from Ravel and Ramanathan (1989). This is based on ERBE data and has spatial features captured by TES observations.



RESULTS (PART 3)

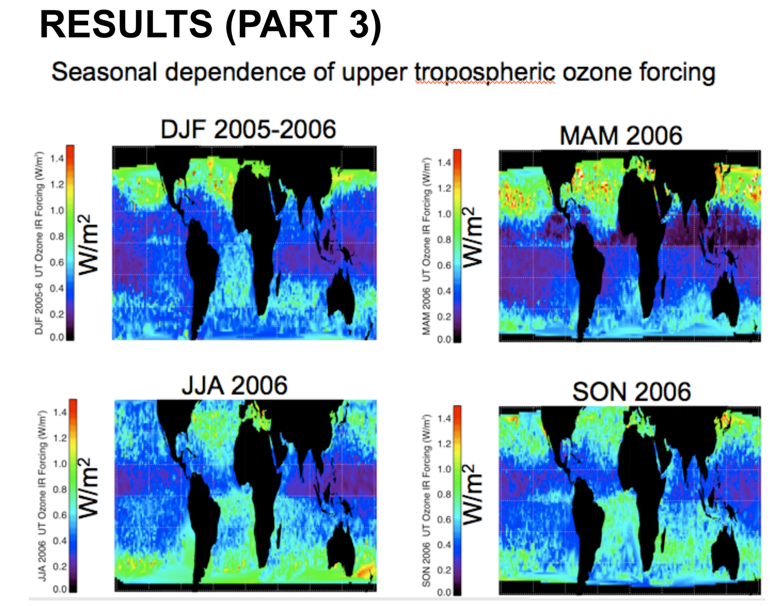


Figure 9. Seasonal maps of ozone IR forcing. The northern hemisphere patterns correspond to the springtime ozone maximum, with some masking due to the impact of water vapor.

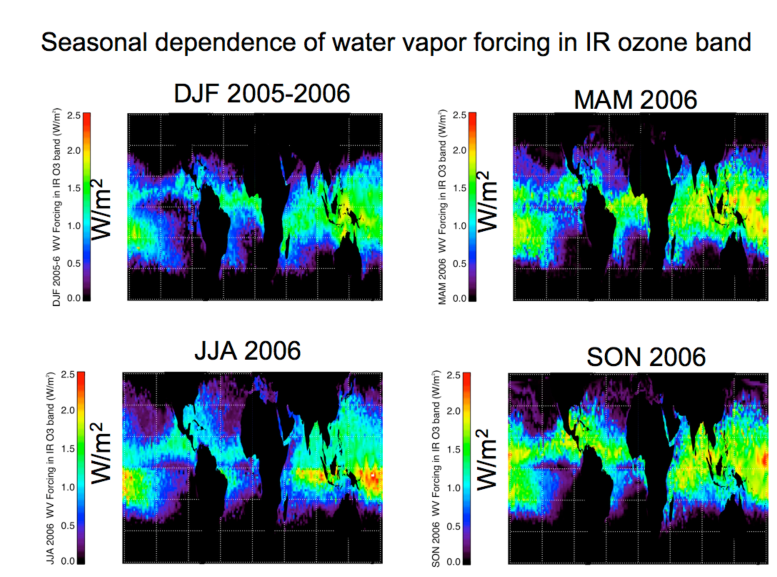


Figure 10. Seasonal maps of the water vapor forcing in the ozone band. The season shift of water vapor north and south, and monssonal moisture is apparent.

SUMMARY

- Using TES spectra, retrieved surface & cloud properties and atmospheric profiles, we can investigate the processes that drive OLR variability.
- We estimate OLR sensitivity to ozone and water vapor by constructing ensemble observations binned by SST. We find an annual average OLR sensitivity to upper trop. ozone of 0.055 W/m²/DU (stddev = 0.017). This is comparable to model estimates but with more sensitivity in the northern hemisphere.
- Using estimated sensitivities, we find instantaneous forcing = 0.48 W/m² (stdev = 0.24 std) for upper trop. ozone (global, annual avg., -45° to 45°)
  - IPCC (2007) value = 0.35 W/m² (range = 0.25 - 0.65) for anthropogenic trop. Ozone
  - 'Medium' level of scientific understanding - need to improve certainty of future predictions
- Instantaneous forcing due to water vapor in the ozone band must be assessed to properly quantify the ozone forcing. The water vapor forcing dominates the radiative budget in the tropics.

FUTURE DIRECTIONS AND MISSIONS

- **In future work, we will examine this radiative forcing over the land by computing spectrally integrated Jacobians (radiance change driven by constituent change) as part of the retrieval process.**
- **Understanding the radiative budget requires us to disentangle the impacts of ozone, water vapor, and clouds.**
- **Future mission designs must include high-spectral measurement, like TES, which are the only way to get at vertical information about ozone, and to separate water vapor, ozone, clouds, and SST.**
- **Future climate missions such as CLARREO, can build off the success of AIRS, TES, IASI, and the science analysis techniques that are rapidly developing.**

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